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RESEARCH ARTICLE

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Shifting to sounders: Whole sounder removal eliminates wild pigs

Alexandra A. Lewis | **Brian L. Williams** | **Mark D. Smith** | **Stephen S. Ditchkoff**

School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849, USA

Correspondence
Stephen S. Ditchkoff, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849.
Email: ditchss@auburn.edu

Present address
Alexandra A. Lewis, Alaska Department of Fish and Game, PO Box 110024 Juneau, AK 99811-0024, USA.

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Abstract

Wild pig (*Sus scrofa*) eradication in demographically open populations has seemed an impossible feat for managers, but more recently, whole sounder removal (WSR) has been proposed as a trapping strategy that has the potential to be successful in eradicating wild pigs from an area. However, little empirical data exist concerning implementation of whole sounder removal strategies. Our objective was to implement and describe wild pig management using WSR. We established a 27-km^2 area (northwest section) where sounders were removed using WSR and a 29-km^2 area (southeast section) where GPS collars were deployed on Lowndes Wildlife Management Area in Alabama. Prior to implementing WSR, we used game cameras over bait at a density of one camera/km^2 in November 2014 and counted 65 and 100 individuals in our northwest and southeast sections, respectively. We began WSR July 2015 and by May 2016, we reduced the estimated population by 90%. However, due to births and seasonal movements of pigs in the periphery of the study area, the population fluctuated between 10–20 individuals from May 2016 to December 2017. In December 2017, we removed the last known remaining sounder, and using game cameras, observed no sounders in the northwest section for the following 7 months, the remaining length of the study. We determined that using the WSR approach can lead to a delay before inevitable recolonization. Therefore, WSR can be a successful tool to significantly reduce a wild pig population and potentially provide managers a pig-free area.

KEYWORDS

invasive species, management techniques, *Sus scrofa*, trapping, whole sounder removal, wild pig

Biological invasions are the introduction, establishment, and spread of nonnative organisms (Mack et al. 2000, Kolar and Lodge 2001, Clout and Russell 2007), and wild pigs (*Sus scrofa*) are a prime example of a biological invader in North America. In the United States, wild pigs cost producers and landowners an estimated US$1.5 billion in yearly agricultural damage and control (Pimentel 2007). In addition, wild pigs carry and transmit parasites and diseases such as pseudorabies and swine brucellosis which are transmissible to native fauna and humans, an issue made more problematic as populations of wild pigs continue to increase (Seward et al. 2004, Engeman et al. 2007, Muller et al. 2019). Wild pigs also compete with native wildlife for resources, depredate herpetofauna, small mammals, and neonates of large mammals (Mayer 2009, Wilcox and van Vuren 2009, Jolley et al. 2010, Suselbeek et al. 2014). Because wild pigs have a wide-reaching impact on native communities, a primary focus of management has been to maximize the number of individuals removed (Campbell and Long 2009).

Wildlife professionals often recommend using a variety of control techniques, such as corral traps and shooting, when managing wild pigs (Campbell and Long 2009, Pepin et al. 2017), and suggest that using a variety of approaches allows managers to avoid habituation to traps (e.g., trap shyness; Campbell and Long 2009, Pepin et al. 2017). However, managers often employ trapping as their primary management tool because it is efficient and economically available to most managers (Williams et al. 2011). However, no trapping programs have ever documented success in eradicating wild pigs in a demographically-open population. The typical measure of success for wild pig control is usually a final or total annual kill count that neglects the number of pigs or sounders left on the landscape. Therefore, portions of sounders—breeding adults or juveniles that quickly rebuild population numbers due to their high rate of reproduction—are left on the landscape (Mayer and Brisbin 2009).

Current management approaches have resulted in documented eradications, such as on Santa Rosa and Santa Cruz Islands, but eradications have mostly been in demographically closed populations (Lombardo and Faulkner 2000, Parkes et al. 2010). Eradication of wild pigs is often considered infeasible in open populations, despite recent data indicating high site fidelity and slow rates of movement across the landscape (Gabor et al. 1999, Sparklin et al. 2009). The ranges and movements of sounders vary depending on resources, but wild pigs typically do not move great distances (Gabor et al. 1999, Kay et al. 2017). In fact, several researchers have reported that sounders maintain exclusive home ranges (Ilse and Hellgren 1995, Gabor et al. 1999, Sparklin et al. 2009). High site fidelity suggests that wild pig populations could be vulnerable to control programs that focus on removing entire sounders. However, most control programs focus on the need to overcome the prolific rate of reproduction rather than exploiting potential vulnerabilities in their biology, such as high site fidelity and tight-knit social groups.

The whole sounder removal (WSR) management strategy was originally founded on the premise that individual and groups of wild pigs could be identified and tracked. Thus, managers are able to develop knowledge of a population, enhancing their ability to eliminate that population (McCann and Garcelon 2008). Whole sounder removal has been used with wild pigs in a number of areas including on Fort Benning, Georgia (Ditchkoff and Bodenchuk 2020). Although WSR has become popular in name, it has yet to be experimentally evaluated. We examined the biological (e.g., social and spatial) and logistical aspects of a WSR program and provide evidence that WSR can effectively eliminate wild pigs existing in open populations.

STUDY AREA

We conducted our study between November 2014 and June 2018 on Lowndes Wildlife Management Area (LWMA) in central Alabama (32°21′46″N 86°44′48″W). Average annual rainfall for LWMA was between 132 and 142 cm, elevation was 44.5 m, average summer high and low temperatures were 34°C and 22°C, respectively, and average winter high and low temperatures were 16°C and 2°C, respectively. Lowndes Wildlife Management Area was a 67-km^2 property located near White Hall, Alabama that was managed by the Alabama Department of Conservation and Natural Resources (ADCNR), Division of Wildlife and Freshwater Fisheries, for game animals such as white-tailed deer (*Odocoileus virginianus*) and eastern wild turkey (*Meleagris gallopavo silvestris*). Land cover classes and vegetation of the area were planted pines (*Pinus* spp.), planted hardwoods (*Quercus* spp.), mixed pine and hardwood forest, wildlife openings, and bottomland hardwoods (Gaston et al. 2008).

We divided Lowndes WMA into northwest and southeast sections (Figure 1). The northwest section where we removed pigs was approximately 27 km^2 and was bounded by the Alabama River on its western, northern, and northeastern sides. Our southeast section of the study area was 29 km^2 bordered by Alabama state highways and agricultural land. The 2 sections were separated by approximately 2.5 km of mixed private and state land composed of agricultural lands, residential area, a gravel mine, and mixed pine and hardwood forests. No removal operations were conducted on the southeast portion of the study area; however, wild pigs were monitored with trail cameras, and some wild pigs from the southeast area were captured and fitted with a GPS (Geospatial Positioning Satellite)/VHF (Very High Frequency) collar. Both areas had pigs that were not naïve to traps. Since their introduction to LWMA by a private citizen in the 1990s, ADCNR personnel have used corral traps, box traps, night shooting, and hunting to manage the population (C. Jawarowski, ADCNR, personal communication). Across LWMA, special hunting seasons for wild pigs occurred for 2 weeks in August and one week in March annually. Outside of the special seasons, wild pigs could be hunted during any other hunting season using the approved weapons and ammunition for those hunts. Removal efforts by adjacent landowners varied, but there were some management efforts on adjacent land to the northwest section using corral and box traps, and night shooting at the gravel mine adjacent to the southeast section.

METHODS

Our WSR strategy was founded on an adaptive 4 step process (Figure 2). Step one was surveying the population. We used trail cameras to systematically survey the study area to locate individuals and sounders prior to removal. Step 2 was to identify individual wild pigs and unique sounders based on pelage characteristics and sounder composition (Sweitzer et al. 2000). We used the images from our camera surveys to identify sounders and optimize our removal locations based on which camera sites were visited most. In step 3, we constructed traps and conditioned sounders to the trap using whole kernel corn. Step 4 was removal and inventory, accounting for which pigs had been removed and which remained. Following the fourth step, we continued to monitor, as in the first step, to ensure that all of the wild pigs in the area had been removed and no others had reoccupied the area.

A preliminary wild pig survey was conducted in late November to early December 2014. Camera densities were approximately 1.25 cameras/km^2, and each site was chosen based on a grid system and either existing pig sign (rooting, tracks, and tree rubs) or a site where we were likely to detect pigs based on proximity to a water source, cover, and food availability (Kay et al. 2017). Sites were prebaited with 12 kg of whole kernel corn and left undisturbed for 7 days prior to camera deployment. After 7 days, 12 kg of whole kernel corn was used to replenish the site and a Reconyx HC500 (Reconyx, Inc., Holmen, WI, USA) trail camera was deployed 1-m high on trees at least 15 cm diameter at breast height. Cameras were set to a 5-minute time lapse interval, and cameras were collected at the end of 7 days. Sites occupied by a sounder were baited continually to keep the sounder in the area until a trap was built and removal or radio collaring efforts could be executed. We defined a sounder as any group of wild pigs with at least one adult female (Graves 1984), based upon estimated body size of >22.7 kg from images (Williams et al. 2011).

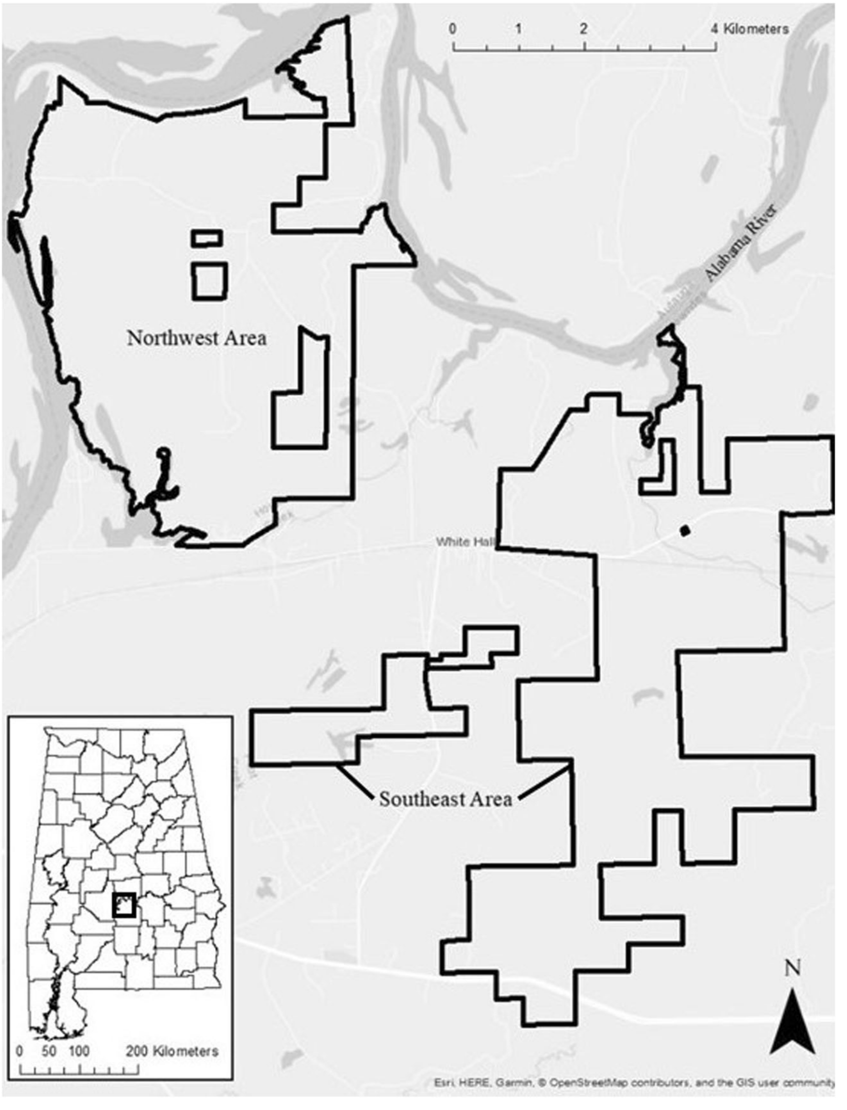

FIGURE 1 Map of Lowndes Wildlife Management Area, in central Alabama, USA. Bold lines outline the borders of the WMA and delineate the northwest (where wild pigs were removed) and southeast study areas (where no removal operations occurred).

Following our initial survey, we began a continual monitoring effort that lasted until June 2018. Our monitoring was conducted using trail cameras to monitor individual wild pigs and sounders. During the continuous monitoring, cameras were sited at locations where initial surveys had documented sounders, where physical sign was present, and at locations where there was a high probability of pig presence (based on water, food, and cover availability; Kay et al. 2017). We deployed and maintained an average of 10 cameras with 7 kg of whole kernel corn until June 2018. We adjusted our continuous monitoring approach for wild pig sounders 3 times each year when trail cameras were required for other surveys during February/March, July, and September. Each February and September, we deployed cameras at a density of one camera/7 km^2. Each March, we deployed cameras at a density of one camera/4 km^2, and each July, we deployed cameras at a density of one camera/1 km^2. Outside of February/March, July, and September, we had an average of 13 cameras (SD = 9.52) in the northwest section per month,

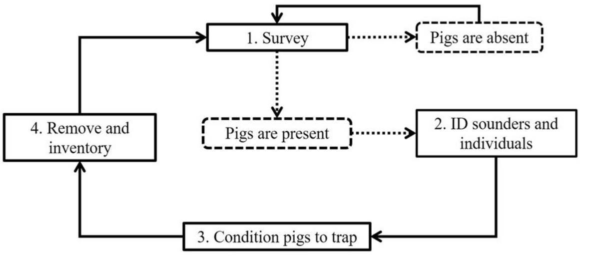

FIGURE 2 The 4 steps of whole sounder removal for a demographically open wild pig population. Step one involves systematically surveying the area to locate individual wild pigs and sounders. Step 2 identifies individuals and sounders based on pelage characteristics, sex, age, and sounder composition. Step 3 is to condition to the trap those pigs that are meant to be removed. Step 4 is to remove the targeted wild pigs and inventory those that were removed and those that may be left on the landscape. Dotted lines are options dependent on the results of the survey.

yielding an average density of one camera/2 km^2, a density greater than one per average wild pig home range size (Sparklin et al. 2009).

We estimated the wild pig population in the northwest section once per month between November 2014 and June 2018. We identified wild pigs by sex, juvenile or adult age class, pelage characteristics, and group composition (Sweitzer et al. 2000). Although our focus was sounders, we counted all wild pigs (adult males, adult females, and juveniles). Juveniles were estimated to be <6 months old whereas adults were ≥6 months old; juveniles were distinguished from adults based on relative size. If pigs with the same characteristics and sounders with the same composition were observed at different camera stations, they were assumed to be the same pigs. If we did not see an individual or sounder for greater than 6 months, we considered those pigs as either dead or emigrated.

We removed sounders between June 2015 and November 2017. When a sounder was targeted for removal, we constructed a corral trap to capture and remove the sounder. We used whole kernel corn to condition sounders to an area and condition them to enter the trap once it was built. The trap consisted of 5, 4.9-m panels attached to 1.6-m t-posts driven into the ground on the outside of the panel. Panels were arranged with a 0.5-m overlap between panels and attached to t-posts with baling wire. In addition, a 2.4-m guillotine-style M.I.N.E.™ Gate (Jager Pro, Fortson, GA, USA) was used as a door and was also attached to t-posts on both sides with baling wire. After traps were constructed, we monitored each trap remotely between 1700 hours and 0600 hours with a Jager Pro M.I.N.E.™ Cam (Jager Pro, Fortson, GA, USA). Wild pigs were habituated to the trap with whole kernel corn until the entire sounder consistently entered. When an entire sounder entered the trap, an observer closed the gate remotely and traveled to the trap to euthanize the trapped pigs.

We defined 3 periods to calculate trapping and monitoring effort: pre-removal monitoring, post-removal monitoring, and no-removal monitoring. Pre-removal monitoring effort was counted from the first night a trap was set and ready to be triggered (i.e., active) to the first night a sounder was removed, and included identifying individuals within a sounder to target for removals. Post-removal monitoring was counted as the nights following an initial removal to when the trap was no longer active (no wild pigs were detected using the trap site). During post-removal monitoring, the trap was maintained in its active state because of the continued presence of wild pigs. No-removal monitoring was when a trap was active, but no removal event occurred at that trap site. When a trigger system or trap failed (i.e., the door closed because of interference with the door mechanism) and the interval between active trapping was <7 days, we considered it part of the same effort sequence. If the interval between active trapping was ≥7 days, we considered it a new effort. We did not quantify our effort into hours because of the remote trigger, nor did we document how many hours were spent constructing or moving traps because of our ability to trigger and monitor traps remotely. Our calculations of trapping effort were only associated with removals and not in efforts to deploy GPS collars.

We deployed GPS collars on individual wild pigs prior to and during WSR to monitor space use on our study area. Specifically, we thought it was important to understand if sounders quickly recolonized areas where wild pigs had been removed or made long excursions to areas such as local agricultural resources. We deployed G2110D GPS/VHF (Advanced Telemetry Systems, Isanti, MN, USA) collars on reproductively mature female pigs (>6 months of age or approximately 40 kg). Adult females in the northwest section were collared in April and May 2015. Once removals began in the northwest, we no longer deployed collars in that section. We deployed GPS collars in the southeast section from May 2015 to November 2017. We targeted 1–2 adult females in each sounder in case one collar failed, to explore space use within and between sounders, and to monitor potential emigration. We trapped adult females using the same trapping method as removals. An observer remotely closed the gate, and then immediately traveled to the trap to restrain and immobilize the adult females. We immobilized wild pigs using an intramuscular injection of Telazol (Fort Dodge Animal Health, Fort Dodge, Iowa, USA; 11 mg/ml given at a rate of 2 mg/kg) diluted with sterile water. We fitted adult females with collars such that the collar could not slip over the sagittal crest. We programmed collars to acquire fixes every 30 minutes, and we monitored collars at least once per month via VHF for mortality or collar failure. The information from these collars was imported into ArcGIS 10.3.1 (ESRI, Redlands, CA, USA) to determine the spatial structure of sounders.

We assumed that data from collars on adult females were representative of the entire sounder based on previous literature (Sparklin et al. 2009). We calculated kernel density home ranges from collars that collected at least 30 days of data with at least 60 locations (Sparklin et al. 2009) using a plug-in bandwidth in adehabitatHR and ks packages in R (Calenge 2006, Duong 2019, R Core Team 2019). Kernel density home ranges were defined as the 95% probability utilization distributions (UD) and the core area as the 50% UD (Gabor et al. 1999). When multiple individuals were collared simultaneously within the same sounder, we used the data for the individual that accrued the most data (Sparklin et al. 2009). We also used the adehabitatHR package to calculate home range overlap of individuals within and between sounders. We used the volume of intersection statistic (VI) to determine overlap between individuals within a single sounder and individuals between sounders (Fieberg and Kochanny 2005) using the 100% UD. The VI was calculated using the full length of a collar's time on an individual and using a truncated version of the data, restricting the data used in the analysis to only when the GPS collars were collecting data at the same time.

RESULTS

We counted 65 and 120 wild pigs on the northwest and southeast sections, respectively, prior to initiating removal efforts in June 2015 (Figure 3). We removed 96 individual wild pigs from 8 sounders during 22 removal events (adult females $n = 15$; adult males $n = 9$; juvenile females $n = 36$; juvenile males $n = 36$). One sounder was removed by a local landowner when it had wandered outside of the LWMA boundaries, and <5 individual wild pigs were removed by hunters during authorized hunting seasons. There were 4 sounders removed in a single removal event (i.e., one night), 2 sounders in 2 removal events, one sounder in 3 removal events, and one sounder over 4 removal events. Among the multiple-event removals, there was an average of 328 days between removals. Between July and October 2015, 69 percent of individuals were removed in 2 main pulses of effort. Subsequent efforts removed fewer total individuals. The final sounder, which consisted of 2 adult females, 2 adult males, and 5 juveniles, was removed in December 2017.

Cumulatively, we used 15 different trapping locations across the northwest section, although wild pig sounders were using the entire study area. We spent 644 total nights ($\bar{x} = 24.8$ nights/effort, SD = 29.6) monitoring a trap that was ready to be triggered (Figure 4). There were a total of 211 pre-removal nights ($\bar{x} = 8.12$ nights/effort, SD = 19.6), 203 post-removal nights ($\bar{x} = 7.81$ nights/effort, SD = 13.3), and 230 nights with no removals associated

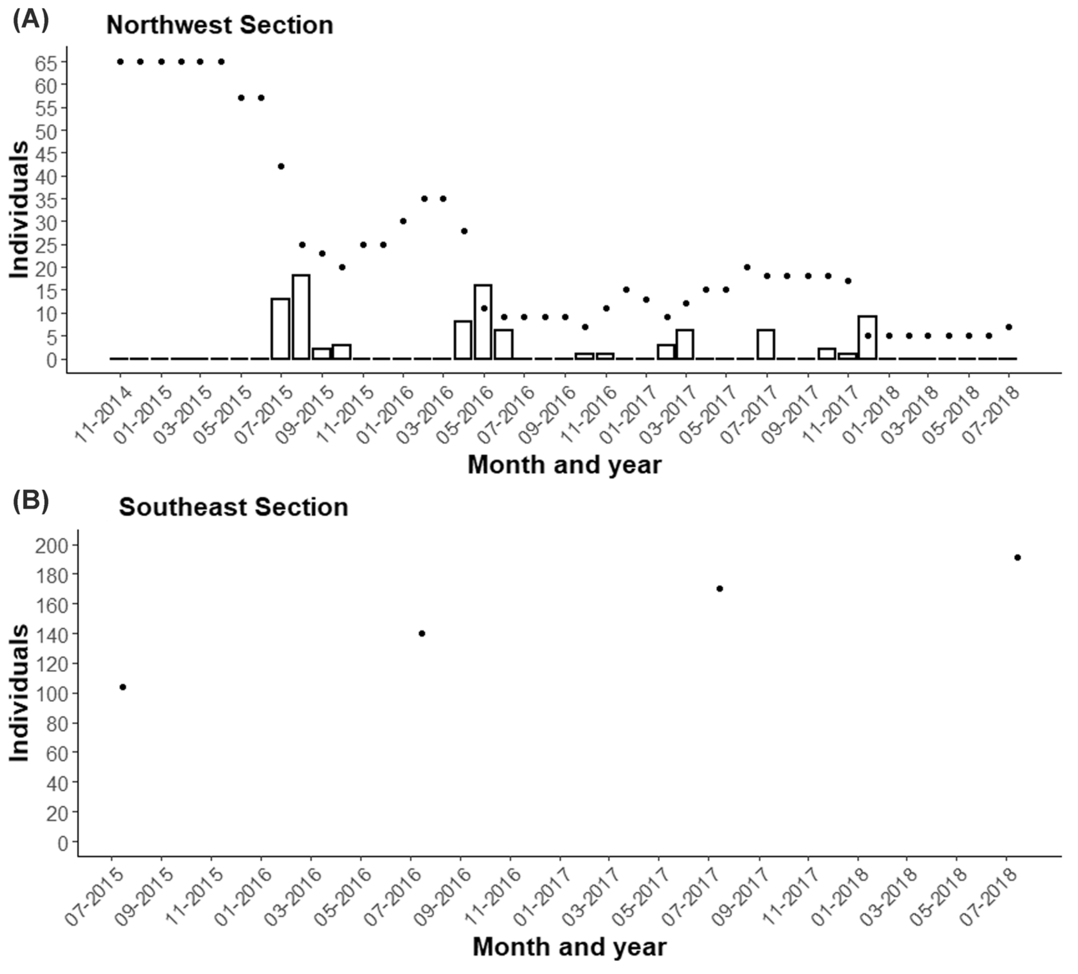

FIGURE 3 Total number of wild pigs present (dots) and total number of wild pigs removed (bars) from the northwest (NW) and southeast (SE) sections of Lowndes Wildlife Management Area, Alabama, USA, between November 2014 and June 2018.

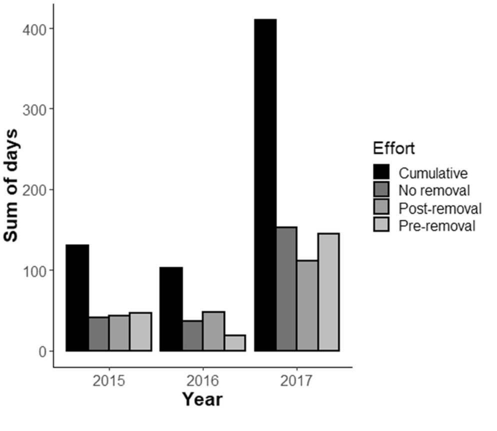

FIGURE 4 Total number of trap nights required for pre-removal, post-removal, and no removal activities during 2015, 2016, and 2017 on Lowndes Wildlife Management Area, Alabama, USA.

(x̄ = 8.85 nights/effort, SD = 18.6). Most individuals from sounders were removed during initial trapping efforts, but 2 separate times a group was trapped during post-removal monitoring because the remainder of the sounder moved out of the trapping area after the initial removal. Cumulatively, we spent a total of 131 nights of effort in 2015 (x̄ = 10.9 nights/effort, SD = 7.06), 103 nights in 2016 (x̄ = 20.6 nights/effort, SD = 16.81), and 410 nights in 2017 (x̄ = 45.6 nights/effort, SD = 41.76). Most effort expended in 2017 was on active traps where there were no removals, but the difference between effort when no wild pigs were removed and effort on pre-removal monitoring was negligible.

We collected GPS locations from 22 adult females from 11 sounders. Five adult females from 3 sounders in our northwest section were collared before removals began in July 2015, and 17 adult females from 7 sounders

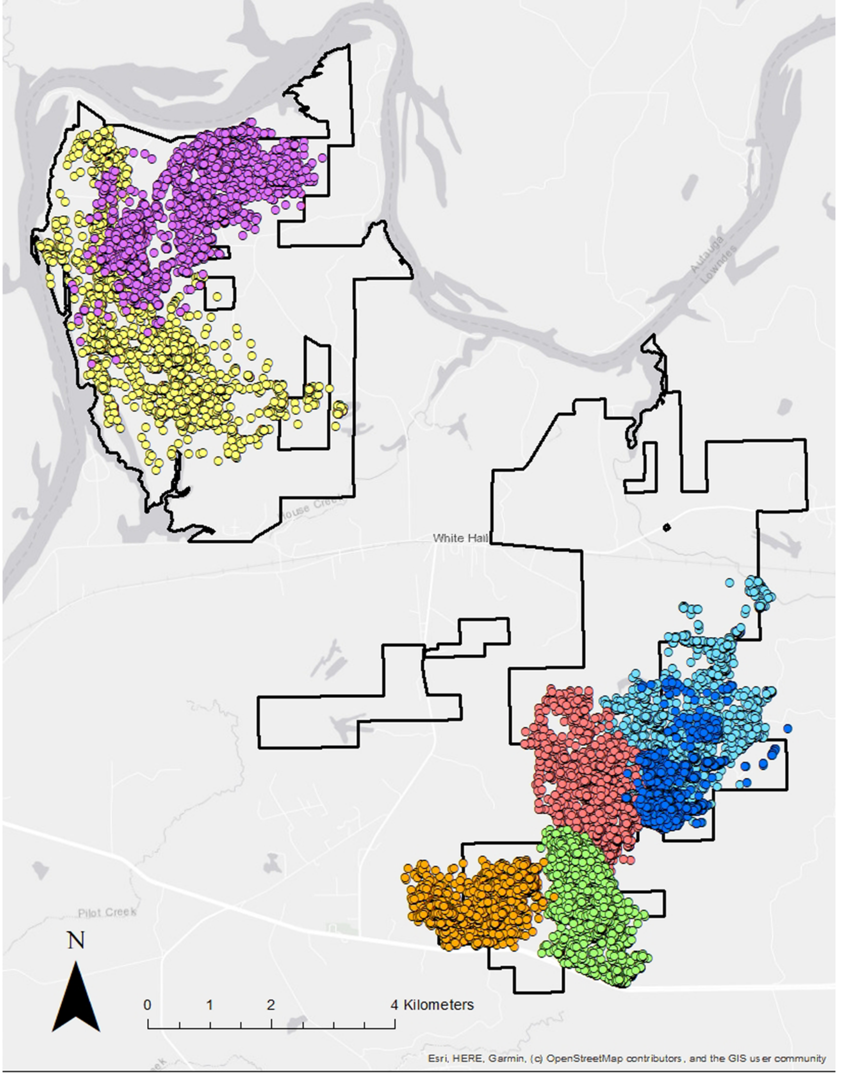

FIGURE 5 GPS locations acquired from 7 radio–collared females on Lowndes Wildlife Management Area from April 2015 to August 2016. Data are only for individual adult females that accumulated greater than 120 days of data. These individuals were from 2 sounders in the northwest section and 4 sounders in the southeast section of the WMA.

that were collared between May 2015 and August 2016 in the southeast section. Collars collected data for an average of 94.9 days (SD = 59.4), ranging from 2 to 217 days. The average number of GPS locations per individual was 4,069 (SD = 1,623). Pairs of individuals within a sounder collared at the same time ($n = 2$ northwest section, $n = 7$ southeast section) collected an average of 7,215 locations per sounder (SD = 3,755; $\bar{x}$ days of overlap = 54, SD = 38). Home ranges calculated with a 95% kernel density utilization distribution from the northwest section ($n = 3$) were 6.2 km^2 (+/−5.31 km^2) and 1.05 km^2 (+/−1.05 km^2) for 50% kernel core areas. Southeast section home ranges ($n = 14$) with 95% kernel density utilization distribution were 3.42 km^2 (+/−0.67 km^2) and 0.67 km^2 (+/−0.35 km^2) for 50% kernel core areas. Though cumulatively some GPS points overlapped, there was no temporal overlap when comparing time stamps between sounders (Figure 5). Of 48 pairwise comparisons between pigs not in the same sounder, 100% utilization distributions overlapped 2.2% (SE = 0.005) when GPS data was clipped for the 2 sets of data to overlap in dates (i.e., only use data when the 2 collars were active within the same time frame). Using the full dataset yielded a volume intersect of 0.038 (3.8%; SE = 0.009). When collared adult females within the same sounder ($n = 6$) were analyzed, volume intersect was an average of 0.824 (82.4%; SE = 0.108) when the data was clipped. Volume intersect using the full set of data within each sounder was 0.692 (69.2%; SE = 0.105).

DISCUSSION

Though ours is not the first study to document the successful removal of wild pigs from an area, ours is the first study to report success in eradicating a demographically open population. However, it should be noted that our population, although demographically open, was bordered on 2 sides by a large river that may have reduced immigration. Our WSR program removed 96 pigs, took 2.5 years using a single employee on LWMA with some assistance from LWMA personnel, and our removals were done with corral traps. Other removal programs have eradicated their demographically closed or isolated populations in a variety of time frames. Channel Islands National Park (215 km^2) eradicated their wild pig population by removing 1,175 pigs over 3 years using a variety of removal techniques (Lombardo and Faulkner 2000). Other examples include Pinnacles National Monument (57 km^2; McCann and Garcelon 2008), Santiago Island (585 km^2; Cruz et al. 2005), Santa Cruz Island (250 km^2; Parkes et al. 2010), and Annadel State Park in California (20 km^2; Barrett et al. 1988). Each example used a variety of techniques including trapping, aerial shooting, and ground hunting over relatively short time frames (3 years) except for Santiago Island. Removal efforts on Santiago Island lasted 30 years.

There were a few reasons why some sounders required multiple removal events. One case was that despite having conditioned the rest of the sounder, there were one or 2 pigs that did not enter the trap at that time, so the trigger operator chose to remove the pigs that had entered the trap and target the remaining pigs afterward. There were also a couple of instances when all pigs in the sounder were in the trap, the trap was triggered, but the delay between pressing the trigger and the trap door closing was long enough to allow one or 2 pigs to escape. We found that the adult females that had been fitted with GPS collars re-entered traps with bait and did not exhibit avoidance of traps. There were 10 individual pigs removed during the study that were not associated with a sounder. After May 2016, the sounders found on camera were those that moved in and out of the LWMA boundary. Any adult males that were removed were either captured in a trap with a sounder or were repeat visitors to a trap that was prepared for a sounder. Incidentally, we found behavioral changes between pigs that were trapped at night and then removed the following morning and pigs that were trapped and removed during the night. In general, trapped pigs responded less to human presence at a trap when approached at night whereas pigs that were approached in the morning were more alert to approaching humans and made more efforts to jump or climb over the trap fence.

Trapping effort during our study was highly variable. Our trapping effort varied among trap sites because some sounders exhibited more elusive behavior and required more trap nights. For example, we expended 90 nights of effort in pre-removal monitoring and 17 in post-removal monitoring to remove one sounder, while another sounder only required 3 days of pre-removal monitoring. Trapping effort between years was markedly greater for 2017 than for 2015 or 2016. The increased effort near the end of the study was a function of the difficulty in trapping due to reduced population size. Most of the last remaining individuals had previously been exposed to traps, and they had likely experienced loss of pigs from their sounders. As a result, complete eradication is much more difficult than population reduction, supporting the assertion of Judge et al. (2017) that complete eradication is often more difficult when there are fewer organisms left on the landscape. Though the assertion of Judge et al. (2017) was made for island populations, removal of the last few individuals on a landscape where the target species can evade removal by moving off the control area (e.g., move off the management area during control operations) indicates that final removal without consistent monitoring will be unsuccessful. Therefore, continual monitoring is a key feature in a WSR program.

The movements of wild pigs in our study suggested there was high site fidelity within sounders and sounders had small home ranges, a characteristic common in areas where resources are readily available (Schlichting et al. 2016). With our GPS collar and trail camera data, we observed that sounders stayed within a range of certain camera sites. Further, a sounder would often revisit a camera site at approximately the same time every day, and some sounders visited the same camera site on a consistent day of the week. Site fidelity is a known attribute of wild pigs (Graves 1984, Keuling et al. 2008) and contributes to the efficacy of WSR. Additionally, our GPS collar data indicated that sounders had minimal spatial overlap and there were no cases of collared individuals making extra-home range movements (Jacobsen et al. 2020) to areas outside of LWMA or between the northwest and southeast sections. In cases when spatial overlap between sounders appeared to occur, a more careful examination of the data indicated that the sounders did not have temporal overlap: either the 2 sounders were not collared at the same time or one sounder was at least 1-km away when another sounder entered its range. Our data suggest that sounders on Lowndes WMA did not overlap in space, which is similar to the findings of Gaston et al. (2008) on the same area. Gaston et al. (2008) reported that wild pigs showed high site fidelity, even when exposed to high hunting pressure. Additionally, our findings are similar to Sparklin et al. (2009) who described territoriality between sounders, and Gabor et al. (1999), who suggested that sounders used exclusive space. In contrast, some earlier studies found that home ranges of sounders consistently overlapped (Boitani et al. 1994). Ilse and Hellgren (1995) reported suspicion of home range overlap, but they did not have empirical data to support that suspicion. However, we are confident that sounders on LWMA did not overlap in their space use, nor did we find evidence that individual wild pigs within sounders intermingled with those of other sounders. Our observations (high site fidelity and no excursive movements) suggest that areas where wild pig sounders are locally eliminated will likely be recolonized slowly. Our study area qualifies as an open population because it is possible for individuals to immigrate onto LWMA. However, barriers like the Alabama River and major highways can negatively impact animal movement, thus further slowing the immigration of surrounding populations onto LWMA (Kay et al. 2017). In areas where wild pigs are found at much lower densities than our study area a pattern of reduced site fidelity could negatively affect WSR programs. In lower density populations, wild pig movements may be difficult to predict or may be more sensitive to disturbance associated with trapping.

The successful elimination of wild pigs from Lowndes WMA was dependent upon continued monitoring efforts throughout the study. Through monitoring, we gained detailed knowledge of the spatial patterns and composition of the wild pig population on Lowndes WMA (McCann and Garcelon 2008). Initial population surveys served to locate and identify sounders that were present when the study began, and continual monitoring following removal events was essential to detect remnants of partially-eliminated sounders. Finally, by continuing camera surveys after sounders were eliminated, we were able to ensure that if sounders did immigrate onto LWMA, we would detect them at an early stage (Barrett et al. 1988). Previously, wild pigs had been successfully eliminated (with the exception of 2 adult females) in an 89-km^2 area of Fort Benning, Georgia, a U.S. military installation, using WSR between 2007 and 2010 (Ditchkoff and Bodenchuk 2020). However, without further management, the wild pigs that were not removed re-colonized the cleared area (Michael Ramirez, Fort Benning, personal communication).

Although our implementation of WSR on LWMA was successful for the duration of this study, without the maintenance of an appropriate monitoring and removal program, the area will likely be recolonized by wild pigs at some point, and potentially return to its previous state.

MANAGEMENT IMPLICATIONS

Our WSR program was predicated on surveillance, and we described a simple way of locating and identifying sounders and the individual wild pigs that comprised the population. We believe that if pigs are not detected in an initial survey, but are present in surrounding properties, immigration is possible and surveying at regular intervals (e.g., every 3 months) will allow for detection of wild pig immigration at an early stage. Our success on Lowndes WMA was heavily dependent on continuous monitoring, identifying sounders, and ensuring the removal of the entire sounder rather than a portion of it. We believe the implementation of WSR across landscapes is feasible as the principle is applicable to wild pig social behavior. Applying WSR to other conditions and terrains may require removal tools different from the heavy, metal corral traps used in our study. However, because the success of our program was dependent on monitoring, not removal technique, we believe that WSR can be successfully implemented anywhere. In addition to providing detailed knowledge of the population prior to removal, our diligence in monitoring, although time consuming, proved effective at documenting the decrease and ultimate elimination of the population.

Although we did not test a multifaceted removal effort where multiple removal techniques were used, WSR may have enabled a more timely and efficient elimination of wild pigs from the study area. Bodenchuk (2014) reported that aerial gunning was a highly efficient technique for removing wild pigs from the landscape. Although aerial gunning is likely not effective at removing entire sounders, it would reduce the number of individual wild pigs in each sounder and may have resulted in improved efficiency at eliminating some sounders. Additionally, a considerable portion of our efforts at removal was focused on the last few remaining animals, which seemed to be trap shy. Use of techniques such as dog hunting during this phase of removal also may have improved our efficiency (Ditchkoff and Bodenchuk 2020).

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CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

ETHICS STATEMENT

All animal handling for captures and euthanasia procedures were approved by the Auburn University Institutional Animal Care and Use Committee (PRN 2014-2555; PRN 2017-3164).

ORCID

Stephen S. Ditchkoff http://orcid.org/0000-0002-7414-5777

REFERENCES

Barrett, R. H., B. L. Goatcher, P. J. Gogan, and E. L. Fitzhugh. 1988. Removing feral pigs from Annadel State Park. Transactions of the Western Section of The Wildlife Society 24:47–52.

Bodenchuk, M. J. 2014. Method-specific costs of feral swine removal in a large metapopulation: the Texas experience. Proceedings of the Vertebrate Pest Conference 26:269–271.

Boitani, L., L. Mattei, D. Nonis, and F. Corsi. 1994. Spatial and activity patterns of wild boars in Tuscany, Italy. Journal of Mammalogy 75:600–612.

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516–519.

Campbell, T. A., and D. B. Long. 2009. Feral swine damage and damage management in forested ecosystems. Forest Ecology and Management 257:2319–2326.

Clout, M. N., and J. C. Russell. 2007. The invasion ecology of mammals: a global perspective. Wildlife Research 35:180–184.

Cruz, F., C. J. Donlan, K. Campbell, and V. Carrion. 2005. Conservation action in the Galàpagos: feral pig (*Sus scrofa*) eradication from Santiago Island. Biological Conservation 121:473–478.

Ditchkoff, S. S., and M. J. Bodenchuk. 2020. Management of wild pigs. Pages 175–197 *in* K. C. VerCauteren, J. C. Beasley, S. S. Ditchkoff, J. J. Mayer, G. J. Roloff, and B. K. Strickland, editors. Invasive wild pigs in North America: ecology, impacts, and management. Taylor and Francis Group, CRC Press, Boca Raton, Florida, USA.

Duong, T. 2019. Kernel smoothing. R package, version 1.11.7. https://cran.r-project.org/package=ks. Accessed 23 Aug 2019.

Engeman, R. M., A. Stevens, J. Allen, J. Dunlap, M. Daniel, D. Teague, and B. Constantin. 2007. Feral swine management for conservation of an imperiled wetland habitat: Florida's vanishing seepage slopes. Biological Conservation 134: 440–446.

Fieberg, J., and C. O. Kochanny. 2005. Quantifying home-range overlap: the importance of the utilization distribution. Journal of Wildlife Management 69:1346–1359.

Gabor, T. M., E. C. Hellgren, R. A. Van Den Bussche, and N. J. Silvy. 1999. Demography, sociospatial behaviour and genetics of feral pigs (*Sus scrofa*) in a semi-arid environment. Journal of Zoology 247:311–322.

Gaston, W. D., J. B. Armstrong, W. Arjo, and H. L. Stribling. 2008. Home range and habitat use of feral hogs (*Sus scrofain*) on Lowndes County WMA, Alabama. Pages 1–17 *in* Proceedings of the 2008 National Conference of Feral Hogs, St. Louis, Missouri, USA.

Graves, H. B. 1984. Behavior and ecology of wild and feral swine (*Sus scrofa*). Journal of Animal Science 58:482–492.

Ilse, L. M., and E. C. Hellgren. 1995. Resource partitioning in sympatric populations of collared peccaries and feral hogs in southern Texas. Journal of Mammalogy 76:784–799.

Jacobsen, T. C., K. H. Wiskirchen, and S. S. Ditchkoff. 2020. A novel method for detecting extra-home range movements (EHRMs) by animals and recommendations for future EHRM studies. PLoS ONE 15:e0242328.

Jolley, D. B., S. S. Ditchkoff, B. D. Sparklin, L. B. Hanson, M. S. Mitchell, and J. B. Grand. 2010. Estimate of herpetofauna depredation by a population of wild pigs. Journal of Mammalogy 91:519–524.

Judge, S. W., S. C. Hess, J. K. Faford, D. Pacheco, and C. R. Leopold. 2017. Monitoring eradication of European mouflon sheep from the Kahuku Unit of Hawai'i Volcanoes National Park. Pacific Science 71:425–436.

Kay, S. L., J. W. Fischer, A. J. Monaghan, J. C. Beasley, R. Boughton, T. A. Campbell, S. M. Cooper, S. S. Ditchkoff, S. B. Hartley, J. C. Kilgo, et al. 2017. Quantifying drivers of wild pig movement across multiple spatial and temporal scales. Movement Ecology 5:1–15.

Keuling, O., N. Stier, and M. Roth. 2008. Annual and seasonal space use of different age classes of female wild boar *Sus scrofa* L. European Journal of Wildlife Research 54:403–412.

Kolar, C. S., and D. M. Lodge. 2001. Progress in invasion biology: predicting invaders. Trends in Ecology and Evolution 16:199–204.

Lombardo, C. A., and K. R. Faulkner. 2000. Eradication of feral pigs (*Sus scrofain*) from Santa Rosa Island, Channel Islands National Park, California. Pages 300–306 *in* D. H. Browne, H. Chaney, and K. Mitchell, editors. Proceedings of the Fifth California Islands Symposium. Santa Barbara Museum of Natural History, California, USA.

Mack, R. N., D. Simberloff, W. M. Lonsdale, H. Evans, M. Clout, and F. A. Bazzaz. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10:689–710.

Mayer, J. J. 2009. Overview of wild pig damage. Pages 221–246 *in* J. Mayer and I. L. Brisbin, editors. Wild pigs: biology, damage, control techniques and management. Savannah River National Laboratory, Aiken, South Carolina, USA.

Mayer, J. J., and I. L. Brisbin. 2009. Introduction. Pages 1–2 *in* J. J. Mayer and I. L. Brisbin, editors. Wild pigs: biology, damage, control techniques and management. Savannah River National Laboratory, Aiken, South Carolina, USA.

McCann, B. E., and D. K. Garcelon. 2008. Eradication of feral pigs from Pinnacles National Monument. The Journal of Wildlife Management 72:1287–1295.

Muller, L. I., N. Poudyal, R. D. Applegate, and C. Yoest. 2019. Control efforts and serologic survey of pseudorabies and brucellosis in wild pigs of Tennessee. Human-Wildlife Interactions 13:167–175.

Parkes, J. P., D. S. L. Ramsey, N. Macdonald, K. Walker, S. McKnight, B. S. Cohen, and S. A. Morrison. 2010. Rapid eradication of feral pigs (*Sus scrofa*) from Santa Cruz Island, California. Biological Conservation 143:634–641.

Pepin, K. M., A. J. Davis, F. L. Cunningham, K. C. VerCauteren, and D. C. Eckery. 2017. Potential effects of incorporating fertility control into typical culling regimes in wild pig populations. PLoS ONE 12:e0183441.

Pimentel, D. 2007. Environmental and economic costs of vertebrate species invasions into the United States. Pages 2–8 *in* G. W. Witmer, W. C. Pitt, and K. A. Fagerstone, editors. Managing vertebrate invasive species: proceedings of an international symposium. USDA/APHIS/WS, National Wildlife Research Center, Fort Collins, Colorado, USA.

R Core Team. 2019. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/. Accessed (date).

Schlichting, P. E., S. R. Fritts, J. J. Mayer, P. S. Gipson, and C. B. Dabbert. 2016. Determinants of variation in home range of wild pigs. Wildlife Society Bulletin 40:487–493.

Seward, N. W., K. C. VerCauteren, G. W. Witmer, and R. M. Engeman. 2004. Feral swine impacts on agriculture and the environment. Sheep and Goat Research Journal 19:34–40.

Sparklin, B. D., M. S. Mitchell, L. B. Hanson, D. B. Jolley, and S. S. Ditchkoff. 2009. Territoriality of feral pigs in a highly persecuted population on Fort Benning, Georgia. Journal of Wildlife Management 73:497–502.

Suselbeek, L., V. M. A. P. Adamczyk, F. Bongers, B. A. Nolet, H. H. T. Prins, S. E. van Wieren, and P. A. Jansen. 2014. Scatter hoarding and cache pilferage by superior competitors: an experiment with wild boar (*Sus scrofa*). Animal Behaviour 96: 107–115.

Sweitzer, R. A., D. van Vuren, I. A. Gardner, W. M. Boyce, and J. D. Waithman. 2000. Estimating sizes of wild pig populations in the North and Central Coast regions of California. Journal of Wildlife Management 64:531–543.

Wilcox, J. T., and D. H. van Vuren. 2009. Wild pigs as predators in oak woodlands of California. Journal of Mammalogy 90: 114–118.

Williams, B. L., R. W. Holtfreter, S. S. Ditchkoff, and J. B. Grand. 2011. Trap style influences wild pig behavior and trapping success. Journal of Wildlife Management 75:432–436.

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